Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

A PYRRHOTITIC PERIDOTITE FROM KNOX COUNTY, MAINE[1]—A SULPHIDE ORE OF IGNEOUS ORIGIN

EDSON S. BASTIN
Washington, D. C.

The rock here described, though of slight areal extent, is of rather unusual interest as a representative of a little-known type of sulphide ores consolidated from a molten magma, and also as the first-described representative of subclass 2 of the perfemane class (class V) of the quantitative system of classification, all of the extremely basic rocks thus far described falling in subclass 1, perfemane, of this class. The rock also shows beautiful examples of reaction rims of hornblende between plagioclase feldspar and olivine, an alteration to which little reference has been made in petrographic literature.

Location and geologic occurrence.—The rock here described occurs on the farm of Mr. Charles A. Millers, about three-fourths of a mile southwest of the village of East Union in the town of Union, Knox County, Maine. It constitutes a single outcrop about forty to fifty feet across. The rock disintegrates rapidly, and the partly disintegrated material has been excavated to some extent for use in improving the roads. All of the present surfaces are rusty, and a number of well-rounded bowlders of disintegration which have withstood weathering longer than other portions lie partially imbedded in the gravelly disintegrated material. The rock is extremely tough and resistant under the hammer.

In the woods, about one-half mile southeast of the outcrop described above, a small prospect pit has been dug in loose ferruginous material, which probably passes below into rock similar to that on the Millers farm.

The above-mentioned localities lie within the area of the Rockland quadrangle, near its western border. The rocks of the region are regionally metamorphosed sediments probably of Cambro-Ordovician age, which have been intruded and further metamorphosed by granitic rocks. The peridotite here described is in all probability intrusive into these sediments. Gabbroid and dioritic rocks whose relations show them to be differentiation products from the granitic magmas are of common occurrence in this region, and the pyrrhotitic peridotite under discussion probably represents an extreme phase of this differentiation process, although it may on the other hand be wholly unconnected in origin with the granitic intrusions.

---

[1] Published with the permission of the director of the U. S. Geological Survey.

MEGASCOPIC APPEARANCE

The megascopic appearance of this rock is so unusual as to attract immediate attention in the field. It is medium-grained (millimeter-grained), holocrystalline, and equigranular, and is composed of a yellowish-gray, metallic-looking mineral, which proves to be pyrrhotite scattered in very irregular masses through a ground-mass which for the most part appears structureless and is dark green to nearly black in color. The form and natural size of the pyrrhotite areas are shown in Fig. 1, which was traced from a polished surface.

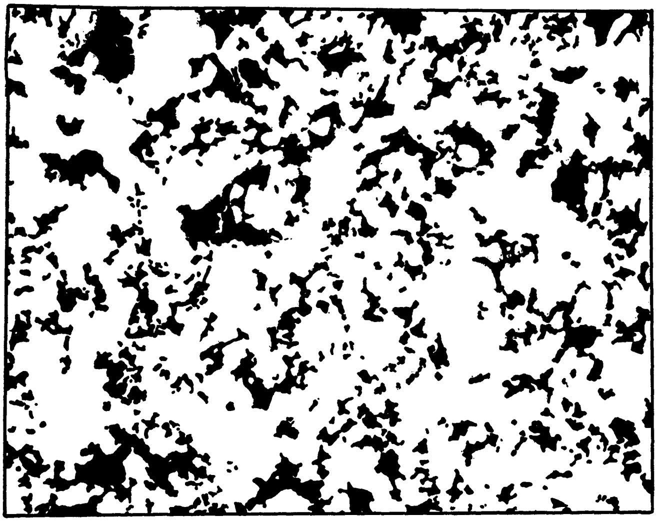

Fig. 1.—Tracing from polished surface of peridotite. The black areas represent pyrrhotite with small associated amounts of chalcopyrite and pyrite. The white areas are occupied mainly by olivine with some hornblende and plagioclase feldspar. (Natural size.)

In irregular association with the pyrrhotite are small amounts of chalcopyrite distinguishable by its yellower tint. Most of the nearly black matrix between the sulphide masses exhibits no trace of cleavage and is shown under the microscope to be olivine, its dark color being due to the abundance of minute magnetite inclusions which it contains. Scattered dark-green or bronze-colored grains in the ground-mass which show distinct cleavage faces are seen under the microscope to be hornblende. Small, scattered areas, gray in color with a dull luster, are plagioclase feldspar. In general the rock is remarkably fresh. Serpentine and chlorite, which have resulted from olivine and hornblende decomposition, are confined largely to certain layers which are thread-like in form as seen in cross-section on a polished surface. These areas of decomposition are largest between closely grouped pyrrhotite masses, and the narrower strands run from one pyrrhotite mass to another and are parallel in their general trend throughout the hand specimen.

The characters and relationships of the various original and secondary minerals which compose the rock are described in detail below.

ORIGINAL MINERALS

Olivine.—This is the most abundant original constituent of the rock, and estimates on six slides show that it makes up about 60 per cent. by volume of the whole rock. Since the specific gravity of the rock is about 3.42 while the average for olivine is in the neighborhood of 3.35, the percentage of olivine by weight would be only slightly less than this figure. The norm shows only 30.99 per cent. by weight of olivine but in addition shows 22.06 per cent. by weight of hypersthene, a mineral not observed in the rock itself. A part of the iron belonging to the hypersthene in the norm appears in the mode in the more siliceous mineral hornblende, while the remainder appears in olivine, a mineral less siliceous than hypersthene.

The olivine occurs in rounded grains ranging from 1 or 2^{mm} to 8^{mm} in length, the majority being between 3 and 4 ^{mm}. Most of the grains are entirely fresh except for a narrow alteration zone of fibrous serpentine about their borders. Certain narrow bands traversing the rock in a manner already described are characterized, however, by much more extensive alteration, and in these areas the olivine grains may be partly or wholly serpentinized, the alteration having, as is usual, been most extensive along the irregular cracks and about the peripheries of the grains. The characteristic appearance of the less altered olivine grains is shown in Fig. 2, in which most of the narrow serpentine borders appear white. The large black area is pyrrhotite.

Pyrrhotite.—Next to olivine, pyrrhotite is the most important mineral of the rock. The analysis shows that it contains small amounts of nickel and cobalt, and constitutes 22.50 per cent. by weight of the whole rock. A small amount of pyrite is also included in this determination and under the microscope this mineral is seen to form a small part of some of the areas between the olivine grains, which are occupied mainly by pyrrhotite. The volume relations between the pyrrhotite (with small amounts of other sulphides) and the other rock constituents may be judged from Fig. 1.

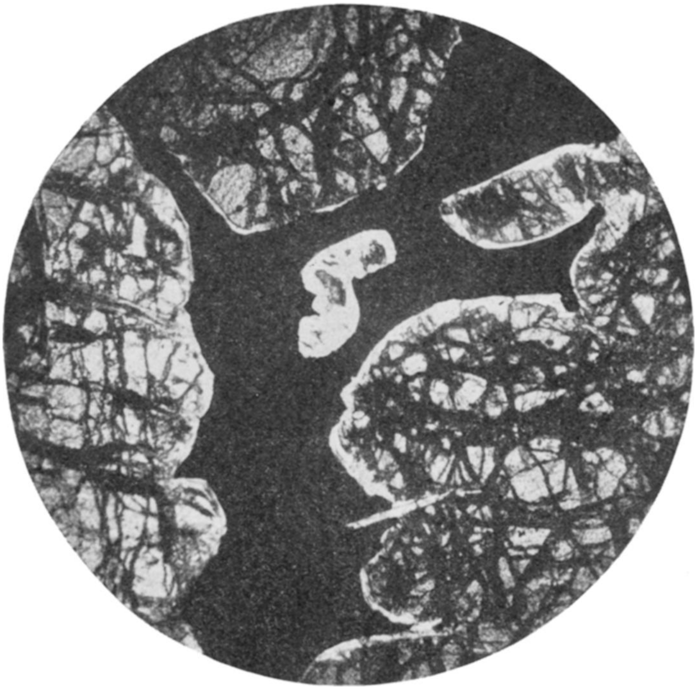

FIG. 2.—Pyrrhotite (black) in characteristic allotriomorphic association with olivine. The dark bands traversing the olivine are lines of magnetite inclusions. The white borders around some of the olivine grains are serpentine. (Magnification about thirty diameters, polarized light.)

As shown in Fig 2, the pyrrhotite is normally completely allotriomorphic with respect to olivine grains, its relations in this respect being similar in every way to those exhibited by the feldspar. The pyrrhotite is also in contact with fresh massive hornblende and with almost unaltered plagioclase feldspar. The allotriomorphic relation of nearly all the pyrrhotite to unaltered grains of the original mineral olivine is considered to be conclusive evidence that practically all the pyrrhotite is an original crystallization from the magma and is essentially contemporaneous with the other principal constituents of the rock. In a few narrow zones traversing the rock, pyrrhotite occurs in angular areas more or less connected with each other and associated with chlorite and hornblende. These very limited portions may be a secondary crystallization.

Feldspar.—In the hand specimens this mineral forms dull-gray areas with irregular outlines, never over one-fourth of an inch and seldom over one-eighth of an inch across. Under the microscope it is found to occupy irregular areas between the rounded olivine grains, with respect to which the feldspar is entirely allotriomorphic. It shows albite and occasionally carlsbad twinning, the angles of the former running up to thirty degrees. The index of refraction as determined on powdered material by the immersion method approximates 1.55. The angle in the section perpendicular to the negative bisectrix between M and the plane of the optic axes is twenty-nine degrees. These results show that the feldspar is andesine-labradorite with approximately the composition Ab_1An_1. These are also the exact proportions in which albite and anorthite are present in the norm as calculated from the analysis.

With the exception of the reaction rims of amphibole described in the section on secondary minerals, the feldspar is in general very fresh though some of it is clouded with aggregates of small, highly refracting plates and flakes. Most of these have indices of refraction which are only slightly greater than that of the feldspar, and are probably muscovite. Others of higher index are probably an amphibole similar to that developed between the feldspar and the olivine.

Hornblende.—The mineral next in importance is hornblende, which, in some parts of the rock, is almost wholly absent, but in other parts is present in large crystals, which are allotriomorphic with respect to the olivine grains. Nearly all of the larger hornblende crystals contain small, rounded olivine inclusions, usually fresh, though sometimes serpentinized. The mineral is identified as hornblende by the rhombic cleavage exhibited in some sections, by its index of refraction, which is intermediate between those of olivine and serpentine, and by its double refraction, which, by comparison of its interference colors with those exhibited by olivine, is found to be about 0.022 to 0.024. Its extinction angles in sections in which the cleavage parallel to *c* is well defined range up to twenty-seven degrees. The pleochroism is usually weak though strong in certain sections. The colors vary from pale pink to pale green and, in some sections, deep brown. There is frequently more or less mottling, due to slight variations in color and birefringence from point to point. The contacts between hornblende and olivine and between hornblende and pyrrhotite are in most cases perfectly sharp, neither mineral having undergone alteration. Between hornblende and feldspar, the contact though normally sharp, occasionally shows evidence of some recrystallization of the hornblende next the feldspar. The abundant small olivine inclusions present in the larger hornblendes seem to indicate that the latter mineral followed very close upon the olivine in crystallization and was probably in part contemporaneous with it. The pyrrhotite and feldspar probably crystallized at about the same time, and followed close upon the hornblende crystallization.

Magnetite.—Magnetite is present only in minute irregular grains scattered through the olivine crystals in bands of varying width, many of which represent fracture planes. The magnetite as seen in the thin sections seems to form from 5 to 40 per cent. by volume of the olivine grains. The average is estimated at at least 10 per cent. by volume or about 17 per cent. by weight. Since the olivine was estimated to constitute about 60 per cent. by weight of the whole rock the magnetite included in it will form 17 per cent. of 60 per cent. or about 10 per cent. by weight of the whole rock. In the analysis all the iron was determined as FeO but in the calculation of the norm a part was apportioned to 10 per cent. of magnetite, the remaining iron forming 5.64 per cent. of FeO. Many of the magnetite bands extend from one olivine grain into another which is in contact with it, but they are nowhere observed to continue into adjacent areas of feldspar, hornblende, or pyrrhotite.

Chalcopyrite.—The analysis shows this mineral to constitute 1.03 per cent. by weight of the rock. In the hand specimens and slides it is seen to be associated irregularly and in small amounts, as was pyrite, with the areas of pyrrhotite.

Pyrite.—Small amounts of pyrite are associated irregularly with the pyrrhotite.

Biotite.—This mineral occurs as a few scattered plates seldom over 0.7^{mm} in greatest dimension, which in some sections are entirely surrounded by olivine. In other cases the biotite occurs in long narrow areas between olivine and pyrrhotite. In one case, which is shown in Fig. 2, a narrow biotite blade lies at right angles to the contact between perfectly fresh olivine and pyrrhotite, penetrating some distance into each of the crystals. In this occurrence at least it is undoubtedly primary, though some of the plates may be of secondary origin.

Spinel.—A few grains of a dark green isotropic mineral occur in certain portions of the rock in irregular association with pyrrotite and hornblende or as inclusions in the latter mineral. Its grains are without regularity in form and range in size up to 0.4^{mm} though mostly under 0.2^{mm}. The mineral is probably pleonaste or chlorospinel.

SECONDARY MINERALS

Serpentine.—This mineral is developed in short, closely aggregated fibers as an alteration product of olivine. Most of it is colorless in the thin section; but rarely light to deep yellow colors occur. Between crossed nicôls it is, in some cases, nearly isotropic, while in other cases showing blue-gray interference colors. The serpentinization begins in the normal manner at the borders of the olivine grains and proceeds inwards along irregular cracks. The degree of serpentinization varies greatly in different portions of the rock, some olivine grains showing only a narrow border of serpentine not exceeding 0.015^{mm} in width along their contact with pyrrhotite and chalcopyrite, while in other cases the olivine grains have been almost entirely serpentinized.

Amphibole.—In addition to original hornblende, whose occurrence has already been described, amphibole occurs as reaction rims between plagioclase feldspar and olivine or pyrrhotite. Most of these zones vary in width from 0.02^{mm} to 1^{mm}, and show a more or less radiate structure, amphibole fibers or brushes being directed about at right angles to the borders of the feldspar crystals. The mineral forming the rims is identified as amphibole by the fact that it is in some places in crystallographic continuity with the massive hornblende already described, by its double refraction (about 0.024), and its index of refraction, which is intermediate between those of olivine and serpentine.

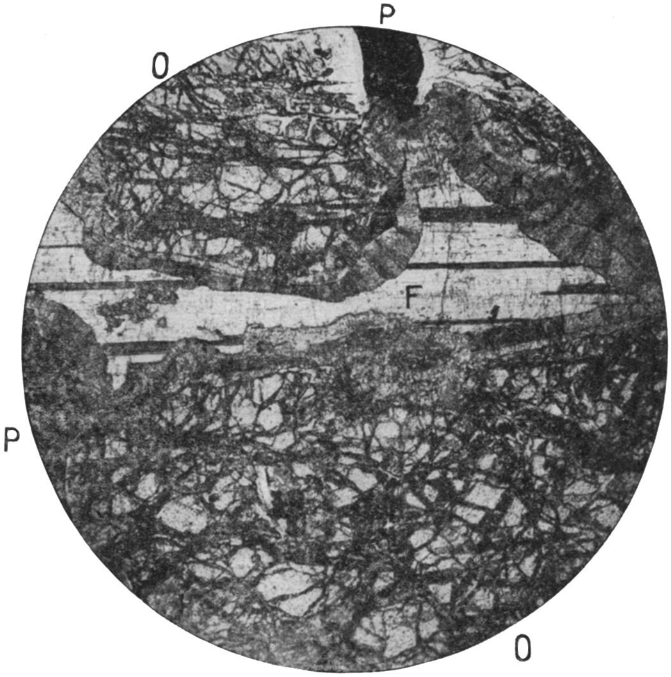

FIG. 3.—Reaction rims of amphibole bordering feldspar. *F* = Feldspar (andesite-labradorite), *P* = Pyrrhotite, *O* = Olivine. Note the double character of the rims between feldspar and olivine, their single character between feldspar and pyrrhotite, and their entire absence between olivine and pyrrhotite. (Magnification about thirty diameters, polarized light.)

Some of these fringe-like borders show two layers of fibers, usually in close contact with each other, but in some cases separated by a narrow band of a non-fibrous hornblende, which usually shows a faint tint of brown. In the double borders developed between plagioclase and olivine, the bands of minute magnetite inclusions so characteristic of the latter frequently continue through the amphibole band nearest the olivine, but are not present in the band nearest the feldspar, a relation which indicates that both these minerals have been involved in the replacement. The layer nearest the olivine is usually nearly colorless while that nearest the feldspar usually shows a pale-greenish tint. Usually, though not invariably, the rim next the olivine is narrower than that bordering the feldspar. Between feldspar and pyrrhotite only a single reaction rim is developed; it frequently is pale brown in color especially near the pyrrhotite.

The general appearance of the reaction rims is shown in Fig. 3. In the more altered portions of the rock, the reaction zones become somewhat broader and in some cases lose their fibrous character probably as a result of recrystallization. Secondary hornblende of this type in some places grades with perfect continuity into original hornblende. Larger crystals of hornblende associated with chlorite and angular areas of pyrrhotite in certain narrow zones traversing the rock are probably of secondary origin. The hornblende of the reaction rims occasionally grades into hornblende of this type.

In seeking to determine what original minerals were the source, partial or complete, of the hornblende of the reaction rims, it is evident that the best results are likely to be obtained from a study of the freshest portions of the rock, where the alterations are in their initial stages. In these parts of the rock hornblende is uniformly absent between the olivine and the pyrrhotite, serpentine being the secondary mineral developed along these contacts. Between the feldspar and olivine and between feldspar and pyrrhotite, however, a reaction rim of hornblende is always present. The darker color exhibited by the hornblende formed along the feldspar-pyrrhotite contact presumably indicates that the mineral here is richer in iron and proportionately poorer in magnesia than that developed next to the olivine. These relations clearly indicate that the hornblende is developed as a result of chemical interchange between plagioclase and the femic minerals, olivine or pyrrhotite.

It is hardly possible, however, to regard this change as taking place without accession of material from outside or loss to other parts of the rock. This follows from a consideration of the chemical composition of the original minerals involved. The feldspar of the rock, andesine-labradorite, has the composition $Na_2O \cdot 2CaO \cdot 3Al_2O_3 \cdot 10SiO_2$ and the olivine $2(MgFe)O \cdot SiO_2$. In the former the molecular proportion of soda to lime is as 1:2. In any reaction in which andesine-labradorite and olivine were involved without outside gain or loss, the resulting product should show a similar proportion between Na_2O and CaO. As shown by the microscopic studies, the resulting mineral is hornblende, but an examination of the available hornblende analyses shows that in nearly every case the soda is greatly subordinate to the lime, the molecular proportions ranging from soda 1 and lime 12 to soda 1 and lime 3, but in no case approaching the proportion of 1:2. The reaction probably involved, therefore, either a loss of soda, or a notable addition of lime, or both. In the more altered portions of the rock the hornblende, as already stated, occurs in larger, massive crystals which occur not alone between feldspar and the femic minerals but in contact with other constituents. In some places areas originally occupied by plagioclase now show only a few feldspar remnants entirely surrounded by hornblende.

Alterations of the type just described are probably of somewhat common occurrence among peridotites though readily traceable only in rocks which show the initial stages of alteration. Few instances are described in the literature. Van Hise[1] makes the following statement in regard to a reaction between olivine and anorthite:

> In some instances the alteration into actinolite is described as taking place in connection with feldspar as a reaction rim. In this case the calcium may be supposed to be derived from anorthite, as calcium silicate. The aluminum may be supposed to pass into common spinel and hercynite (isometric; sp. gr. 3.93), which are well known to be alteration products of olivine. The reaction may be

$$\underbrace{4Mg_3FeSi_2O_8}_{\text{Olivine}} + \underbrace{4Ca\,Al_2Si_2O_8}_{\text{Anorthite}} = \underbrace{Mg_9Fe_3Ca_4Si_{16}O_{48}}_{\text{Actinolite}} + \underbrace{3MgAl_2O_4}_{\text{Common spinel}} + \underbrace{FeAl_2O_4}_{\text{Hercynite}}.$$

Törnebohm in a description of some of the diabases and gabbros of Sweden describes an alteration to hornblende almost identical with that observed in the Maine rock.

> The alteration of the olivine, as usually exhibited in the rocks under discussion, proceeds exclusively from the borders of the grains. There forms next to it a

---

[1] C. R. Van Hise, *Treatise on Metamorphism*, Mon. XLVII, U. S. Geological Survey, pp. 310, 311.

colorless zone showing a radial structure, and, especially where the olivine is in contact with plagioclase, there is present always a second more or less regular zone with similar structure. The latter is made up of an aggregate of green, rather highly dichroic grains, all of which are hornblende. It seems as if these zones were developed in consequence of a reaction between the plagioclase and the olivine, the inner zone being formed at the cost of the latter, and the outer zone at the cost of the former. The reaction zone is of particularly constant occurrence between olivine and plagioclase, but between olivine and augite it is absent and if augite penetrates in wedge-like form between olivine and plagioclase then the two zones separate, the green remaining between the augite and the plagioclase and the lighter zone between the olivine and the plagioclase, though both soon wedge out. Neither by heating nor by acids were the zones notably affected. In the much weathered portions of the rock the olivine inside the bright zone is more or less completely altered to a dirty-green mass of serpentine."[1]

THE FOLLOWING ANALYSIS OF THE ROCK IS BY DR. W. F. HILLEBRAND[2]

SiO_2	28.04	TiO_2	.20
Al_2O_3	3.51	P_2O_5	.04
Fe_2O_3	14.95[3]	MnO	.24
FeO		SrO	trace?
MgO	21.97	CO_2	1.01
CaO	1.78	Fe_7S_8	21.53[4]
Na_2O	.28	NiS	.94[5]
K_2O	.08	CoS	.03[5]
H_2O+	2.54	$CuFeS_2$	1.03
H_2O-	1.48	Total	99.65

Chlorite and calcite.—These minerals occur only in the more weathered portions of the rock in association with massive secondary hornblende and recrystallized (?) pyrrhotite. The chlorite belongs to the chlinocore variety and is mostly light green in color though a few of the larger and more massive grains are a deep grass green. The interference colors between crossed nicols vary from greenish yellow and dark gray in the light-green portions to very dark gray in the deep green. The mineral is, in part at least, the product of hornblende decomposition. Calcite occurs in small, irregular crystals and in aggregates of minute grains associated with chlorite, and also as a few larger grains associated mainly with secondary hornblende.

---

[1] A. E. Törnebohm, "Ueber die wichtigeren Diabas und Gabbro-Gesteine Schwedens," *Neues Jahrbuch für Mineralogie*, 1877, pp. 382, 383. Translation by E. S. B.

[2] Laboratory of U. S. Geological Survey.

One hundred grams of pyrrhotite were tested for platinum, but none was found.

[3] The iron was calculated as FeO. Some is present as Fe_3O_4, which would raise the summation. The figure for the oxides of iron is only approximate because of the impossibility of calculating the amount of pyrite or the exact composition of the other sulphides.

[4] Includes some pyrite.

[5] Occurs combined with or closely associated with pyrrhotite.

The olivine grains contain so much magnetite in the form of inclusions that they adhere strongly to a magnet. From microscopic examination it was estimated that the magnetite formed about 17 per cent. by weight of the olivine or approximately 10 per cent. by weight of the whole rock. The iron belonging to the 14.95 per cent. of FeO in the analysis (11.63 per cent. of Fe) was redistributed on the basis of 10 per cent. of Fe_3O_4, the total of the rock constituents thus being raised to 100.34 per cent.

CALCULATION OF THE NORM FROM THE ANALYSIS

	Percentage Weights	Mol. Proportions	Cal.	Or.	Ab.	An.	Cor.	Rut.	Hy.	Ol.
SiO_2	28.04	467		6	24	16			212	209
Al_2O_3	3.51	34		1	4	8	21			
Fe_3O_4	10.00									
FeO	5.64	81							27	54
MnO	.24									
MgO	21.97	549							185	364
CaO	1.78	31	23			8				
Na_2O	.28	4			4					
K_2O	.08	1		1						
H_2O	4.02									
TiO_2	.20	3						3		
P_2O_5	.04									
CO_2	1.01	23	23							
Fe_7S_8	21.53									
NiS	.94									
CoS	.03									
$CuFeS_2$	1.03									
Total	100.34		23	1	4	8	21	3	212	209

Orthoclase	.56	Salic 7.02
Albite	2.10	
Anorthite	2.22	
Corundum	2.14	
Rutile	.20	Femic 86.78
Hypersthene $\begin{cases} FeO \cdot SiO_2 = 3.56 \\ MgO \cdot SiO_2 = 18.50 \end{cases}$	22.60	
Olivine $\begin{cases} 2\,FeO \cdot SiO_2 = 5.51 \\ 2\,MgO \cdot SiO_2 = 25.48 \end{cases}$	30.99	
Nickel- and cobalt-bearing Pyrrhotite	22.50	
Magnetite	10.00	
Chalcopyrite	1.03	
Water	4.02	
Calcite	2.30	
P_2O_5	.04	
	100.16	

Class .... $\frac{\text{Sal.}}{\text{Fem.}} = \frac{7.02}{86.78} = < \frac{1}{7}$ =V, perfemane.

Subclass.............. $\frac{\text{POM}}{\text{A}} = \frac{63.25}{23.53} = < \frac{7}{1} > \frac{5}{3}$ =2, dofemone.

Order................ $\frac{\text{PO}}{\text{M}} = \frac{53.05}{10.00} = < \frac{7}{1} > \frac{5}{3}$ =2, dopolic, Mainare.

Section............... $\frac{\text{P}}{\text{O}} = \frac{22.06}{30.99} = < \frac{5}{3} > \frac{3}{5}$ =3, pyrolic, Mainiare.

Rang................ $\frac{(\text{MgFe})\text{O} + \text{CaO}}{\text{K}_2\text{O} + \text{Na}_2\text{O}} = \frac{29.63}{.36} = > \frac{7}{1}$ =1, permirlic.

Section............... $\frac{(\text{MgFe})\text{O}}{\text{CaO}} = \frac{27.85}{1.78} = > \frac{7}{1}$ =1, permiric.

Subrang .... $\frac{\text{MgO}}{\text{FeO}} = \frac{21.97}{5.88} = < \frac{7}{1} > \frac{5}{3}$ =2, domagnesic, Lermondose

Since the rock shows a slight amount of alteration the norm computed above can be regarded only as approximating that of the fresh rock. The rock, however, falls well within the limits of each of the divisions in the above classification, and it is not probable that the weathering has produced changes sufficient to change its position in the quantitative classification.

The name Lermondose which is here proposed for the rock is derived from Lermond Pond, situated about one mile northeast of its type exposure. The ordinal name Mainare is a reference to the state of Maine, in which the rock occurs.

Bearing on the origin of certain sulphide ores.—Chalcopyrite is present in such small amounts and the percentages of nickel and cobalt associated with the pyrrhotite are so small that the rock has no present economic value as an ore. The sulphides are also associated in such an intimate way with the other rock minerals as to make their complete separation difficult. The rock, nevertheless, exhibits an unusual concentration of metallic sulphides common in many ore deposits, and from a theoretical standpoint at least may be regarded as an example of ore formed by original crystallization from the molten magma. It seems but a short step from a rock of this type to one in which chalcopyrite is present in sufficient amounts or in which the percentage of nickel or cobalt in the pyrrhotite is large enough to give the ore commercial value. The existence of commercial deposits of sulphide ores of such purely igneous origin has, so far as known to the writer, never been satisfactorily demonstrated, but the possibility of their existence can hardly be questioned in view of the known occurrence of igneous rocks as rich in sulphides as the one here described. That this rock is itself a differentiation from a less basic magma is shown by the occurrence about one-quarter mile northeast of the Millers farm of a much less basic rock belonging apparently to the same intrusion but containing relatively small amounts of pyrrhotite. The original characters of this rock are obscured by intense weathering, which has reduced the rock to an irregular aggregate of pale-green chlorite, pale-green or brown amphibole, much of it fibrous, and calcite.

Sulphide-bearing rocks of the type here described are, however, even more suggestive in their bearing on workable ore deposits when we take into account the possibilities of local sulphide enrichment by aqueous or pneumatolytic action. There is no evidence of such enrichment at the locality near East Union, nor do the rocks of the surrounding region contain ore veins of any kind. It is evident, however, that such processes acting upon a rock of this type would be fully capable of producing ore deposists of a commercial character.

Adams,[1] Coleman,[2] and Barlow[3] of the Canadian Geological Survey have all attributed the primary concentration in the copper, nickel, and cobalt ores of the Sudbury district of Ontario to magmatic differentiation in a magma which normally crystallized as a norite or gabbro, while admitting the importance in this region of secondary concentration by aqueous agencies. Vogt has expressed similar views of the genesis of the sulphide ores of the Scandinavian nickel deposits. On the other hand Posepny[4] has affirmed that the original crystallization of pyrrhotite in any notable quantities is a chemical impossibility, and the views of Adams, Coleman, and Barlow have been challenged by a number of writers partly on theoretical and partly on observational grounds.

While affirming nothing in regard to the origin of the ore deposits

[1] F. D. Adams, *Canadian Mining Bureau*, January, 1894, p. 8.

[2] A. P. Coleman, *Bureau of Mines Report*, Ontario, 1905, Part III, and this JOURNAL, Vol. XV, pp. 759–82, 1907.

[3] A. E. Barlow, *Summary Report of the Director of the Geological Survey of Canada*, 1901.

[4] "The Genesis of Ore Deposits," *Transactions of American Institute of Mining Engineers*, 1893.

of either of these regions, the writer believes that such occurrences, as that near East Union demonstrate beyond question that pyrrhotite, in very considerable percentages, may occur as an original crystallization from igneous magmas, and the possibility of at least a primary concentration of this sort must be recognized in the study of the origin of sulphide ores, particularly those of nickel and cobalt.